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Review

The next protein transition☆

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A B S T R A C T

Background: Meeting the UN Sustainable Development Goals requires a relatively rapid transition towards a circular economy. Therefore, a multidisciplinary perspective is required to sketch why a transition from diets based primarily on animal proteins towards diets based primarily on plant proteins products is extremely urgent for both food security and sustainability.

Scope and approach: This review starts out by identifying ecological, economic and social aspects of sustainable food consumption. Subsequently, it is argued how protein supply is underlying and linking the top-3 of anthropogenic impacts based on the planetary boundaries concept, i.e. 1) biodiversity loss, 2) nitrogen cycle acceleration, and 3) carbon cycle acceleration (resulting in climate change). These environmental impacts associated with current Western food consumption need to be reduced urgently. In order to address the inefficiencies inherent to current dietary patterns, therefore, a ranked list of more sustainable options is proposed, based on their order of magnitude. Addressing consumers, industry, and governmental stakeholders plus cultural aspects, challenges and options are sketched.

Key findings and conclusions: Clearly, a dietary transition from primarily animal towards plant protein products is required. Fortunately, new dietary guidelines are increasingly taking sustainability into account and the contours of a diet transition are slowly emerging.

1. Introduction

In September 2015, the United Nations (UN) General Assembly adopted the 2030 Agenda for Sustainable Development. As an integral part, 17 Sustainable Development Goals (SDGs) present a novel approach and incentive to prioritize and integrate a number of pressing issues, including food security, food sustainability, climate change, and the broader aim of staying within planetary boundaries. It is evident that a transition towards a circular economy is urgently required to meet the SDGs. Since many of the planetary boundaries are strongly interlinked with protein supply, the goal of the current review is to sketch novel trends, resuming where the preceding one (Aiking, 2011) left off. After summarizing and evaluating the impacts of protein production by sustainability pillar, options to reduce these impacts will be identified and ranked with the help of a framework for priority setting. The role of stakeholders including governments, industry and consumers will be highlighted.

The 17 SDGs form a perfect starting point for this review. Among the 17 SDGs adopted (UN, 2015), food security (SDG 2) evidently ranks higher than climate action (SDG 13). That is only natural, because in 2017 the global population reached 7.5 billion, but even in the medium growth scenario the UN (2017) project a world population of 8.5 billion by 2030 and almost 10 billion by 2050. Furthermore, increasing urbanization and incomes will result in diets containing more animal products (FAO, 2017a). The FAO project a 60% food demand increase by 2050 (Alexandratos & Bruinsma, 2012), while many others project a doubling (see: Tomlinson, 2013). During the previous millennium, crop yield increases more or less kept up with demand, but yield increases are slowing down (Ray, Mueller, West, & Foley, 2013). In contrast with the FAO's optimistic view, therefore, several financial institutions foresee that food prices may rise rapidly during the next decades, which might fuel conflict and migration (Natalini, Jones, & Bravo, 2015). KPMG, a global auditor, in fact forecast a 70–90% food price increase by 2030 (de Boer & van Bergen, 2012).

Analysis of the trends since the previous review will highlight changes at the production and consumption side. Food production is accelerating, and so are its environmental impacts. Still, smallholders produce half the world's food (Johnson, Dudley, & Alexander, 2017), but development financing remains a bottle-neck (FAO, 2017a). On the consumption side, there is a dual diet transition in progress. Booming economies are increasing their consumption of meat (China) and dairy (India) like Western Europe did half a century ago (Grigg, 1995). In Europe, a reverse transition away from animal products is about to break through (Geijer, 2017). With respect to sustainability, this is none too early, for there is a growing consensus that animal protein has disproportionate environmental impacts, particularly when produced in intensive production systems employing massive use of feed crops (Aiking, 2014; McMichael, Powles, Butler, & Uauy, 2007; Smil, 2001;

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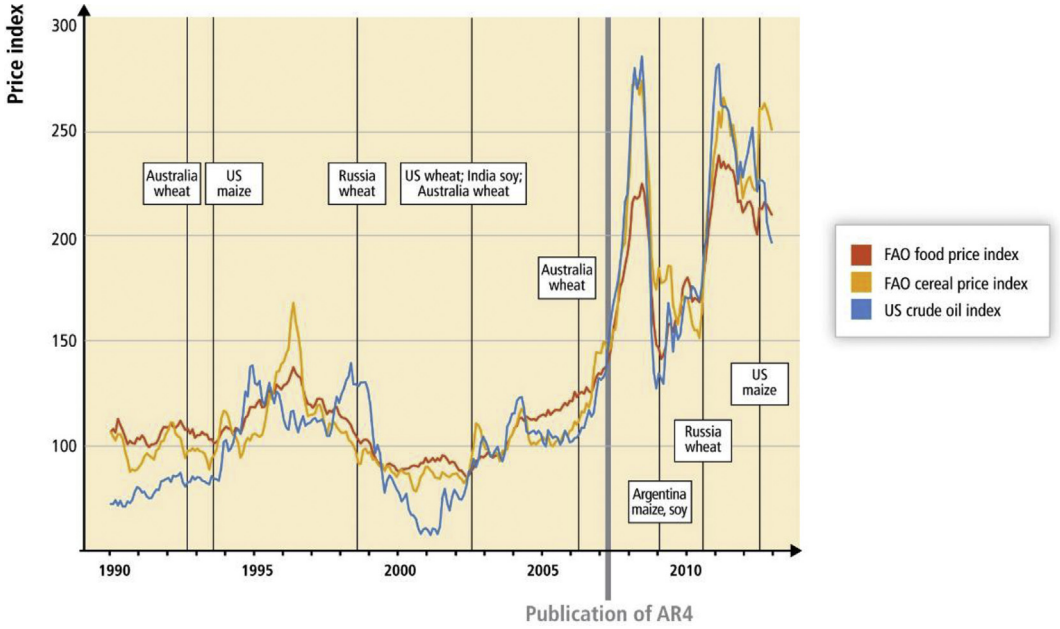

Fig. 1. Food, cereal and crude oil indexes 1990–2013 (Source: Porter et al., 2014, p. 595).

Steinfeld et al., 2006; Westhoek et al., 2011).

2. Ecology

In 2009, Rockström et al. quantified a dozen planetary boundaries (Rockström et al., 2009), including biodiversity loss, nitrogen cycle disruption, climate change (i.e. carbon cycle disruption), phosphate cycle disruption, ocean acidification, land-use change, freshwater use and stratospheric ozone depletion. Subsequently, they were ranked (Aiking, 2011) and put in the above order based on their current transgression (Aiking, 2014). Taken together, the Rockström boundaries can be seen as the carrying capacity of planet Earth, in terms of safe rates of natural resource use and emission of pollutants. Human society may be the primary target of phosphate depletion, but – without exception – Earth's ecology is targeted by each of the eight anthropogenic impacts listed above, either by pollution (such as acidifying emissions), or by resource appropriation (such as taking freshwater and land away from natural habitats). In fact, eutrophication, climate change, ocean acidification, hunting, fishing, land conversion, and freshwater use all contribute to biodiversity loss in unison, explaining its high ranking. With respect to biodiversity loss, intensive livestock farming plays a major role both through the immense land area in use for feed crops (over 400 million hectares; one third of all arable land) (Tilman, Cassman, Matson, Naylor, & Polasky, 2002; Van Zanten, Mollenhorst, Klootwijk, Van Middelaar, & de Boer, 2016) and by ammonia emissions from livestock manure (Erisman, Sutton, Galloway, Klimont, & Winiwarter, 2008; FAO, 2017a; Machovina, Feeley, & Ripple, 2015). The magnitude of livestock's impact on biodiversity was illustrated by Zalasiewicz (2016): “We humans have obviously left our mark on the earth's biological landscape as well. In particular, our species – a very minor player amid the planet's biota even a few thousand years ago – is now the dominant predator on land and sea. We appropriate roughly a quarter of the earth's total biological production for our needs. As a result, we make up about a third of the mass of all land vertebrates (based simply on body weight), and the handful of species we have engineered to become our food make up most of the other two thirds. Wild animals, pushed to the margins, constitute 5 percent or less.” In other words, the ratio wildlife: humans: farm animals = 5: 30: 65 (by weight). Considering the projected doubling in meat demand from 229 million tons in 2000 to 465 million tons in 2050 (Steinfeld et al., 2006), a rough estimate shows that land vertebrates living in the wild may be reduced to 1–2 percent by 2050. Not surprisingly, even the intermediate SSP2 scenario by UNCCD foresees severe deforestation and land conversion in South Asia, Middle and South America, and disastrous damage to tropical forests in Sub-Saharan Africa (Johnson et al., 2017, p. 112).

3. Economy

Half the world's food is produced by smallholders, for example, the share of farms smaller than 2 ha is 97% in China, 85% in South Asia, 68% in the Near East and North Africa (FAO, 2017b, p. 54). Nevertheless, the associated economic power does not rest with smallholders. Lack of land ownership and availability of capital are important bottlenecks driving them out, and critical parts of the food system are becoming concentrated in fewer hands (FAO, 2017a). A few powerful trade corporations, supermarket chains and financial institutions play important parts. Animal protein products such as meat and dairy are important to them from an economic perspective, but when employing intensive production systems these are wasteful of plant protein from an environmental point of view and inherently, therefore, wasteful of the resources required to grow feed crops, such as land, water, phosphate and fuel. More and more, food and feed crops are competing for these increasingly scarce resources. In fact, by 2030 “peak oil” has been foreseen. By the same year, “peak phosphate” has been forecast (Cordell, Drangert, & White, 2009). In addition, “peak water” has been defined (Gleick & Palaniappan, 2010), and a globally operating bank projected a 40% freshwater deficit by 2030 (Crowder, Fumasi, Soccio, Twomey, & Williamson, 2016). Finally, the pressures on land resources are increasing steeply, also leading to compaction by heavy equipment, erosion, and deteriorating soil quality (FAO, 2017a; Johnson et al., 2017; Pimentel & Burgess, 2013), with negative feedback on further production increases.

In light of the above it is no wonder that KPMG, a global auditor, forecast a 70–90% food price increase by 2030 (de Boer & van Bergen, 2012), because every little thing seems to converge then. Since it is their core business, it stands to reason that financial institutions, primarily, issue such a warning of impending danger. Interestingly, however, the latter is confirmed by an unexpected ally. Unprecedentedly, in their AR5 (5th Assessment Report), the IPCC incorporated a chapter on

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food security (Porter et al., 2014), showing a diagram with a time series of food price, cereal price, and crude oil indexes (Fig. 1). As shown, these indexes behaved in parallel, and initially they were rather constant, fluctuating only slightly. In 2006 an increase started, with spikes in 2007–2008 and 2011–2012. Apart from increased volatility, extrapolation of the baseline shows roughly a doubling of the food price index from about 200 in 2012 to about 400 in 2030, in line with the KPMG forecast.

4. Society

The volume and type (animal vs. plant protein; intensive vs. extensive production systems) of protein production have evident impacts on society, primarily on food security. Moreover, undernutrition is often caused by a lack of protein, rather than a lack of calories. In children under 5 years of age, protein undernourishment is a leading cause of death (McLeod, 2011, p. 6). Although hunger and famines are roaming in developing countries primarily, food insecurity in developed countries should not be underestimated. For example, Browning et al. note that "Food affordability is a critical issue that is likely to rise in prominence. Many millions of people currently struggle to be able to afford to eat enough, let alone to eat well and healthily. There are over 4 million people in the UK currently living in food poverty." (Browning, Hirsch, & Lang, 2013).

With respect to poverty alleviation and rural development, of course, sustenance farming by smallholders (Johnson et al., 2017) and smallholder inclusion by multinational enterprises (Sjauw-Koen-Fa, Blok, & Omta, 2016) constitute important aspects. In addition, land grabbing and increasing conflict take their toll (Johnson et al., 2017). The situation in Africa is particularly alarming, because most of the world's population growth in the next few decades will take place there. Such will no doubt lead to unprecedented migration and urbanization (Johnson et al., 2017). The latter generally leads to diet change entailing increased proportions of processed foods and animal products. These are associated with malnourishment, obesity and related diseases such as diabetes and certain types of cancer (McMichael et al., 2007).

In addition to health impacts deriving from consumption, there are health impacts resulting from the ever-increasing production of animal protein. The latter include emerging zoonotic diseases, such as avian influenza, human CJD (Creutzfeldt-Jakob Disease) related to bovine BSE (Bovine Spongiform Encephalopathy, or mad cow disease), Q fever, EHEC (enterohemorrhagic *E. coli*), SARS (Severe Acute Respiratory Syndrome), MERS (Middle East Respiratory Syndrome), etc. (Browning, Pennington, & Rooker, 2009; World Bank, 2010). Primarily due to indiscriminate use of antibiotics in livestock farming, increasing microbial antibiotics resistance, such as by MRSA (methicillin-resistant *Staphylococcus aureus*), is another effect of intensive animal protein production on human health requiring rapid improvement. Of particular concern is the fact that by 2030, antimicrobial consumption has been projected to double in countries such as China and India (Van Boeckel et al., 2015), and that globally two-thirds of the estimated future growth of usage of antimicrobials is expected to occur within the animal production sector, with use in pig and poultry production predicted to double (FAO, 2016).

Another societal issue may be animal welfare (FAO, 2017c; Godfray & Garnett, 2014), which is stronger in Western than in many other countries. Finally, politicians anywhere tend to spare farmers and voters. Consequently, environmental decision making is slow.

5. The pivotal role of protein

The pivotal role of protein is becoming clear in several ways. With respect to food security, the metric of choice is generally calories per capita, even though undernourishment with minerals and vitamins is taken into account (FAO, 2017c). However, as argued above, malnutrition is often caused by a lack of protein, rather than a lack of calories, and a leading cause of death in children under 5 years of age (McLeod, 2011, p. 6).

With respect to food sustainability, climate change is often considered paramount. However, about a dozen of the most important environmental issues were listed by Rockström et al. (2009), who identified and quantified several boundary values that should not be transgressed. Subsequently, these were ranked by Aiking (2014), showing that food production is an important driver of all of them, without exception. Moreover, he argued that Rockström et al.'s top three (1. biodiversity loss, 2. nitrogen cycle disruption, 3. carbon cycle disruption – leading to climate change; transgressed by factors of > 10, 3.45 and 1.1–1.5, respectively) are strongly interlinked by protein production, with nitrogen cycle acceleration in a pivotal role.

By the increasing amounts of animal proteins produced in intensive systems, i.e. with high input of feed crops, the global nitrogen use efficiency keeps dropping, and merely 17% of the nitrogen from fertilizers ends up in human mouths (Erisman et al., 2008). The remainder is lost to the environment, with increasing impacts on terrestrial biodiversity (resulting from ammonia emissions due to degradation of livestock manure) (Sutton et al., 2011), aquatic biodiversity (via eutrophication caused by manure and fertilizer run-off) (Carstensen, Andersen, Gustafsson, & Conley, 2014), climate (due to the tremendous amounts of energy required for the production of nitrogen fertilizers) (Goucher, Bruce, Cameron, Koh, & Horton, 2017; Smil, 2001) and health (McMichael et al., 2007). Conversion losses from plant to animal protein by livestock metabolism are 85% on average, of both (reactive) nitrogen and (embedded) energy (Smil, 2000). Furthermore, intensive animal protein production requires 10-1000 times more water than plant protein (Aiking, 2011; Smil, 2000). In addition to pollution by reactive nitrogen (see above), impacts on biodiversity result from resource appropriation (land and freshwater) and land-use change (Johnson et al., 2017). Considering the anticipated trends in animal protein demand in the next few decades, continued increase in all of these impacts will be inevitable.

6. Diet transition priorities

In the next three decades, more food should become available in absolute terms. The good news is that there is a lot of slack in the food system. In fact, even food price increases may have a positive side in that they will reduce food waste, as well as demand of animal protein. Furthermore, just following dietary guidelines would reduce GHG emissions significantly, in addition to being much healthier than current dietary habits (Macdiarmid et al., 2011). Even cutting the climate change impact in half is feasible by adopting a culturally acceptable and cheap diet (van Dooren, Tyszler, Kramer, & Aiking, 2015). Nevertheless, the UN fail to provide direction and initiate a concerted action, so it is up to stakeholders at the national level, i.e. governments, industry and consumers. In order to make progress swiftly, some priority setting is required.

For the food system to become more sustainable it should be made more efficient. From early on it was noted that losses and waste should be reduced all along the global food supply chain and in the household, in particular (Eberle & Fels, 2016; FAO, 2017a; Kummu et al., 2012; Parfitt, Barthel, & Macnaughton, 2010; Ventour, 2008). The consumer phase is important primarily because roughly one third of purchases in Western supermarkets is discarded before consumption (Ventour, 2008). As a first step towards developing a framework to improve Western consumption, Alexander et al. (2017) established that the magnitude of over-consumption of food, however, surpasses that of food wasted in the household. Within Western over-consumption as such, protein is evidently more important than fats and carbohydrates, both numerically and environmentally, because the average protein intake in many Western countries is 150–200% of recommended values (Aiking, 2014; de Boer & Aiking, 2018). Therefore, reducing consumption of protein and calories should be ranked as first and second

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Table 1
Improving current Western dietary patterns (in descending order of magnitude).

1	Reducing over-consumption of protein
2	Reducing over-consumption of calories
3	Reducing food waste in the household
4	Replacing animal protein with plant protein (analogues and/or whole foods)

options, respectively, for turning current Western consumption in a more sustainable direction by reducing household food waste should be in third place (Table 1). Finally, replacing animal protein products (meat and dairy) with plant protein products (analogues and/or whole foods such as beans and nuts) should be ranked fourth, because their inputs and impacts are somewhat reduced, but not averted. In summary, Table 1 provides a ranked list of potential improvements of current Western consumption patterns.

It has to be kept in mind that there is a dual protein transition in the world. In booming economies animal products are increasingly consumed, and in Western countries a slow decrease set in. Therefore, the appearance of the above table strongly depends on the dietary patterns extant in the countries under consideration. Ethical arguments such as equity, animal welfare, and application of fresh fish and meat resources as pet food (De Silva & Turchini, 2008; Okin, 2017) have cultural dimensions, as well. At any rate, in addition to quantitative impacts, qualitative aspects relating to feasibility also play a part, and will be addressed in the consumer section below. Next to consumption-related improvements, the resource use and pollution associated with production should also decrease along the whole chain. To meet that goal, reducing losses, waste and other emissions are in order. In the production chain, the importance of nitrogen fertilizer has become evident once more, because in a wheat-to-bread supply chain it was shown that the ammonium nitrate fertilizer used in wheat cultivation contributed no less than 43 per cent of greenhouse gas emissions in a full life cycle assessment of a loaf of bread (Goucher et al., 2017). Besides, the importance of food-demand management for climate mitigation had been argued explicitly, confirming that healthy and sustainable food largely go hand-in-hand (Bajzelj et al., 2014). In that respect it is interesting to note that the Dutch GPA (Green Protein Alliance) formulated some SMART goals concerning the protein transition. According to this alliance of industry, academia, NGOs and government, the current Dutch consumption ratio of animal protein: plant protein of 60: 40 should be changed, via 50: 50 by 2025, into 40: 60 by 2050 (Green Protein Alliance, 2016). Within their Programme for a Circular Economy (Ministry for the Environment & Ministry of Economic Affairs, 2016), the Dutch government instated Transition Teams in cooperation with industry, academia and NGOs. Even more interesting, therefore, is the fact that the GPA goals were adopted in full in the Transition Agenda Food & Biomass, also aiming for 10–15% total protein intake reduction per capita by 2050 (Transition Team Biomass & Food, 2018).

7. Consumers

Consumer responses to a potential protein transition have only been studied in a number of (developed) countries, including Australia (Hoek, Pearson, James, Lawrence, & Friel, 2017), the United States (de Boer, de Witt, & Aiking, 2016), member states of the European Union (de Boer & Aiking, 2018), and Switzerland (Siegrist, Visschers, & Hartmann, 2015).

The studies show that most consumers in these countries are not yet prepared to make the associated diet changes (for a detailed review see also: Hartmann & Siegrist, 2017). Moreover, policy-makers in government, industry, and NGOs are often reluctant to engage with this topic (Laestadius, Neff, Barry, & Frattaroli, 2014; Lang, 2012). An additional

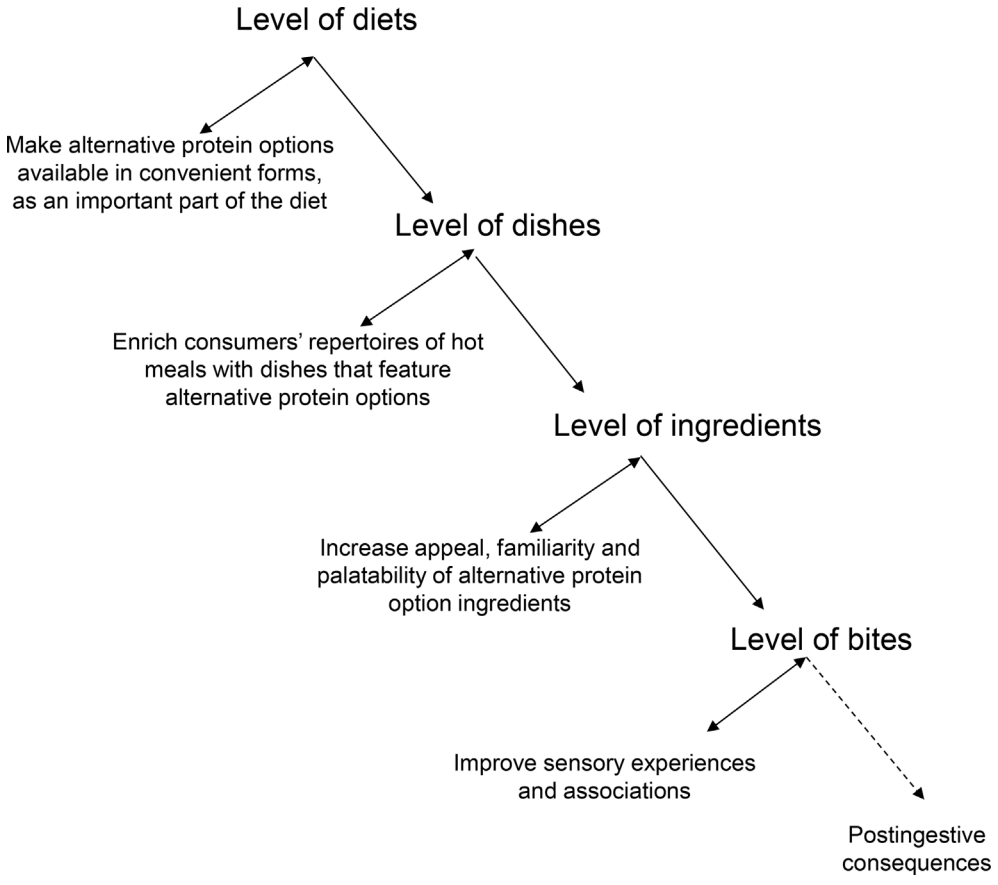
Level of diets
Make alternative protein options available in convenient forms, as an important part of the diet
Level of dishes
Enrich consumers' repertoires of hot meals with dishes that feature alternative protein options
Level of ingredients
Increase appeal, familiarity and palatability of alternative protein option ingredients
Level of bites
Improve sensory experiences and associations
Postingestive consequences

Fig. 2. Targets of change strategies at the levels of diets, dishes, ingredients and bites.

difficulty is that food choice is a seemingly simple, but in fact very complicated behaviour that is influenced by many interacting factors, which cannot be captured by monodisciplinary, single-level research (Köster, 2009). Key to a transition is reducing meat-centred meals and/or replacing them with meals that are based on alternative protein options (e.g. pulses, vegetables, nuts, mushrooms, algae, seaweed, animal by-products, insects). Such a change needs to take place at different levels of detail and context. As described in the literature (Meiselman, 2009) and depicted in Fig. 2, these levels range from diets (i.e. the broad set of food items that is accepted by a population over a period of time), dishes (i.e. food items accepted on a plate in combination with each other), to ingredients (i.e. food items accepted as separate entities) and bites (i.e. single food exposures). Each of these levels – and their interactions – should be considered in order to develop and evaluate realistic, nutritionally, environmentally and culturally acceptable changes in dietary patterns of populations and subpopulations (Masset et al., 2014; van Dooren, Marinussen, Blonk, Aiking, & Vellinga, 2014). Fig. 2 demonstrates that alternative protein options should become an important part of the diet and consumers' repertoire of dishes as well as their set of appealing protein ingredients. Various recent initiatives are exploring this approach.

One of the few examples of an ambitious diet change programme was initiated by gastronomic, nutritional, and environmental specialists in the Nordic countries, who developed a new regional (Nordic) diet in accordance with healthy dietary recommendations, such as more calories from plant foods and fewer from meat, and more locally grown food in season, including food from the sea and the wild countryside (Mithril et al., 2012). By presenting the new diet under the Nordic label, which already had positive connotations in other domains, the initiators tried to connect to lifestyle changes that are collective and highly visible (Byrkjeflot, Pedersen, & Svejenova, 2013). From a sustainability perspective, it has been calculated that the New Nordic Diet has, in theory, substantial environmental and socioeconomic advantages (Saxe, 2014). An early study among a sample of overweight consumers found that the diet had high eating acceptance (tasty) but low practical acceptance, which the researchers attributed to perceived high price, low product availability, and time-consuming cooking procedures (Micheelsen, Havn, Poulsen, Larsen, & Holm, 2014). The latter might be mitigated through the development of more convenient and cheaper versions of the diet as well as by providing guidance regarding meal ideas, meal planning, and cooking skills. Hence, the Nordic initiative demonstrates that to effectively stimulate diet changes, the practical aspects at the level of dishes and ingredients are of utmost importance. Moreover, other research shows that consumers may have the impression that they are unable to fit healthy eating into what they see as their complex lives, with constraints of time, work and social pressures (Macdiarmid, Loe, Kyle, & McNeill, 2013). These barriers make it important to ensure that the recommended changes do not depend solely on individual decisions but become an integral part of regional social and cultural processes with which individuals can identify themselves.

At the level of protein ingredients and their interactions with dishes and bites, there is an increasing interest in mixed food concepts in which part of the protein consumed is from plant-based origin and the rest from animal-based origin. These concepts include flexitarian lifestyles, mixed (instead of meat-centred) dishes, and hybrid protein products. The term “flexitarian”, coined in 1992 (Glowka, Melancon, & Wyckoff, 2004), is a union of the words “flexible” and “vegetarian”, which has been used by individuals who saw themselves as vegetarians occasionally eating meat. From an alternative perspective, however, the term has recently been reframed to highlight the lifestyles of moderate meat-eaters who do not eat meat every day (de Bakker & Dagevos, 2012). On a meat-free day, their dishes may involve a replacement of meat with a vegetarian version of a meat product, such as a veggie burger, or a variety of vegetables and legumes (Schösler, de Boer, & Boersema, 2012). A distinct but overlapping category of moderate meat-eaters is focussing more on smaller portions of meat, which may be of a better quality, such as organic or free-range meat (Heerwagen, Andersen, Christensen, & Sandøe, 2014; de Boer, Schösler, & Aiking, 2014). Moderate meat-eaters may also like mixed dishes, based on recipes that involve a partial replacement of meat. For regular meat-eaters, however, a partial replacement may be associated with a loss of sensory appeal, which might be compensated by changes at the level of dishes, for instance, by stimulating sensory properties using the flavour of spices (Spencer & Guinard, 2018). This type of research also shows that the combination of the protein ingredient and the rest of the dish has a large impact on consumer responses (Elzerman, Hoek, Van Boekel, & Luning, 2011). Changes at the level of protein ingredients, interacting with bites, may include the development of hybrid products, such as beef burger and sausage analogues (Neville, Tarrega, Hewson, & Forster, 2017). Although these products may not be appreciated by “purists” who prefer authentic sources of either meat or environmentally-friendly proteins, such as lentils and seaweed, a hybrid meat product can be acceptable to consumers who are lowly involved with food (de Boer, Schösler, & Boersema, 2013). However, some pitfalls should not be ignored. Although their current market share is very small, meat and dairy analogues are strongly on the rise (Geijer, 2017; Schmidinger, 2012). Yet, their environmental impact reduction is limited compared to consumption reduction, and further improvement of their environmental performance is clearly required (Smetana, Mathys, Knoch, & Heinz, 2015; Van Mierlo, Rohmer, & Gerdessen, 2017). Another point is that food choices may be influenced by fads and fashions. For instance, launching new products that contain a high level of proteins may be useful in professional sports, but for the general public experts consider this as a typical food fad (Seidell & Halberstadt, 2018).

The results of the recent initiatives can be translated in some strategic recommendations:

Increase awareness of the impacts of animal-based protein on the environment, the urgency of this issue and the availability of solutions, but take into account that science-based health and sustainability arguments in favour of a diet change do not sufficiently reach consumers or are too difficult for them to comprehend (de Boer & Aiking, 2017).

Seek ways in which culinary, health and environmental aspects can complement each other. A regional approach may be necessary to bring gastronomic, nutritional, and environmental specialists together and to involve a range of commercial stakeholders, such as farmers, food processors, retailers, restaurant owners and new kinds of food networks.

Pay attention to mixed strategies and flexible options at the levels of diets, dishes, ingredients and bites. Focus on alternative protein options and take into account that these should become an important part of consumers' diet, their repertoire of dishes as well as their set of appealing protein ingredients.

Develop change options that build on the familiar culinary principles of variety, balance, and moderation, as well as a moderate amount of novelty, and create an affordable diet that is convincingly healthier and more sustainable but not much different from the current one, for instance, due to correspondences in meal ideas, ingredient sourcing, culinary skills and social expectations.

Support consumers who find it difficult to adopt the diet and who need help with ‘protein’ literacy. Ensure that the recommended changes do not depend solely on individual decisions but become an integral part of regional social and cultural processes with which individuals can identify themselves.

8. Conclusion

The SDGs hold great potential in prioritizing and integrating the different dimensions of food production and consumption, which is urgently required. In order to meet the rapidly increasing demand, food production grew and intensified in parallel (Godfray & Garnett, 2014; Tilman, Balzer, Hill, & Befort, 2011; Tscharntke et al., 2012). So, for a

number of reasons, the current food system is not sustainable. First, food *production* is appropriating increasingly unsustainable amounts of natural resources (e.g. land, water, energy and nutrients) with harmful impacts on ecology, economy and society (also known as the three pillars of sustainability). Second, food production leads to pollution (e.g. emissions of reactive nitrogen compounds, greenhouse gases, pesticides, antibiotics and biological agents) with unsustainable impacts on biodiversity (ecology) as well as on human health (society). Third, intensive production leads to erosion and decreasing soil quality, with negative feedback on further increases (economy). Finally, access to food is inequitable, leading to hunger and malnutrition, on the one hand, and to excessive food wastage, over-consumption and obesity, on the other hand. Thus, food *consumption* does not have impacts on human health, exclusively, but huge overall impacts on ecology, economy and society.

Following the planetary boundaries concept (Rockström et al., 2009; Steffen et al., 2015), Aiking (2014) argued that their top-3 (1. biodiversity loss, 2. nitrogen cycle acceleration, and 3. carbon cycle acceleration) are strongly interlinked by protein production, with nitrogen cycle acceleration in a pivotal role. European protein supply (= production + import – export) in is over 100 g/capita/day (de Boer & Aiking, 2018), which is almost twice the DRI (daily reference intake). Actual consumption may be 25–30% lower than supply, so conservatively reducing the average EU protein consumption by one third was recommended for health and sustainability as long as one decade ago (Aiking, de Boer, & Vereijken, 2006).

In order to make Western food consumption patterns more sustainable, a number of options were identified and ranked in order of decreasing magnitude. First, over-consumption of protein should be reduced, because ecologically it is the most costly nutrient and the average consumption in many Western countries is over 150% of recommended values (de Boer & Aiking, 2018). Second, over-consumption of calories should be reduced, because health-wise it is the most costly nutrient, and because over-eating was found to be at least as large a contributor to food system losses as consumer food waste (Alexander et al., 2017). Third, in the whole chain, food waste should be reduced, in particular, consumer food waste in Western countries (on average, about one third of supermarket purchase value). Fourth, animal (protein) products (such as meat and dairy) should be replaced with plant (protein) products, because of the low conversion efficiency (ca. 15%) from crop protein to animal protein in intensive production systems involving massive use of feed crops (Aiking, 2011; Smil, 2000).

Moreover, Smil summarized: “Thinking about the road ahead we must recognize several fundamental realities. Solutions will not come from voluntary meatless diets, mass production of mock meat (transformed plant proteins) or muscle tissues cultured in bioreactors. Substituting meat intakes by consumption of other high-protein animal foodstuffs is of marginal help. At the same time, meat production based only on truly sustainable grazing, feeding of forages rotated with food crops, and maximum use of crop and processing residues is inherently limited and although, once it is reoriented toward producing less beef and more pork and chicken, it could supply a surprisingly large share of today's meat consumption (as I will show, close to 70% of 2010 supply) it will not be able to satisfy global demand anticipated for 2030 and even less so for 2050. Innovations and productivity improvements alone cannot prevent further increases in already significant environmental burden of meat production and to reduce them we will also need to moderate our meat consumption.” (Smil, 2014, p. 68). We couldn't agree more.

The problem is that few of the stakeholders involved – government, industry, consumers – are inclined to consumption reduction, or even promoting it. In fact, they are looking to one another to take the initiative (Roberts, Crossley, & Barling, 2013). Fortunately, some consumer groups seem to be sensitive to flexible diet concepts offering a moderate amount of novelty, as shown above in the section on consumers. As mentioned before, it is important to seek ways in which culinary, health and environmental aspects can complement each other (de Boer & Aiking, 2017). In that respect, it is important to note that dietary guidelines are increasingly addressing sustainability in addition to healthy nutrition. In 2015–2016, these included Sweden, UK, Germany, and The Netherlands, as was shown in two reviews (Behrens et al., 2017; Fischer & Garnett, 2016). In the USA, the 2015 Dietary Guidelines Advisory Committee's recommendations to the same effect (DGAC, 2015) were not ratified by the US Senate. Therefore, important sustainability issues (Sabaté, Harwatt, & Soret, 2016) were omitted from the latest US guidelines. That is unfortunate, because health may be key to entice consumers to drop their conservative attitudes and progress towards a diet transition, which would benefit both the environment, and their health via reduction of obesity and sequelae (Hadjikakou, 2017; You & Henneberg, 2016). In fact, there is increasing evidence that nutritionally healthy diets – i.e. according to dietary guidelines – generally go hand in hand with sustainable diets (Buchner et al., 2011; Mason & Lang, 2017). In that respect, a diet containing less animal products would benefit both public health and environment, but completely doing away with animal protein products would not be optimal for either (Van Kernebeek, Oosting, Van Ittersum, Bikker, & de Boer, 2016). Western diets do not have to go completely vegetarian, therefore, but reducing total protein intake as well as the ratio of animal over plant protein, as a proposed dual goal (Transition Team Biomass & Food, 2018), would significantly cushion the shocks to ecology, economy, and society that appear to be in store for the next three decades.

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